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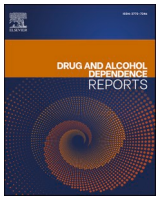

How substance use preferences and practices relate to fentanyl exposure among people who use drugs in Rhode Island, USA

Leah C. Shaw [a], Katie B. Biello [a,b,c], Jane A. Buxton [d,e], Jacqueline E. Goldman [a], Scott E. Hadland [f], Susan G. Sherman [g], Yu Li [a], Alexandria Macmadu [a], Brandon D.L. Marshall [a,*]

[a] Department of Epidemiology, Brown University School of Public Health, Providence, RI, USA
[b] Department of Behavioral & Social Sciences, Brown University School of Public Health, Providence, RI, USA
[c] The Fenway Institute, Fenway Health, Boston, MA, USA
[d] BC Centre for Disease Control, Vancouver, BC, Canada
[e] School of Population and Public Health, The University of British Columbia, Vancouver, BC, Canada
[f] Division of Adolescent and Young Adult Medicine, Massachusetts General Hospital for Children, and the Department of Pediatrics, Harvard Medical School, Boston, MA, USA
[g] Department of Health, Behavior and Society, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA

HIGHLIGHTS

- Fentanyl preference and confidence about exposure predict fentanyl presence.
- Younger age, male sex at birth, injection drug use is associated with fentanyl presence.
- Results show substantial variation in the presence of fentanyl among PWUD.

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ABSTRACT

Background: Over 107,000 people died in the United States (U.S.) from drug overdose in 2022, with over one million overdose deaths since 1999. The U.S. drug market is characterized by a highly toxic, unregulated, and rapidly changing supply. Understanding the extent of exposure to fentanyl among people who use drugs (PWUD) will guide public health interventions aimed to decrease overdose.
Methods: We utilized baseline data from the Rhode Island Prescription and Illicit Drug Study, a randomized controlled trial of harm reduction-oriented interventions for PWUD in Rhode Island from 2020 to 2023. We evaluated sociodemographic and drug use-related covariates and examined fentanyl presence in urine drug testing (UDT). We built a classification and regression tree (CART) model to identify subpopulations with the highest likelihood of fentanyl presence in UDT.
Results: Among 446 participants, those with fentanyl present in UDT tended to be younger, non-Hispanic white, and had recently injected drugs ($p<0.05$ for all). The CART analysis demonstrated a large variation in sample sub-groups' likelihood of fentanyl presence in UDT, from an estimated probability of 0.09 to 0.90. Expected recent fentanyl exposure was the most important predictor of fentanyl in UDT.
Conclusions: Univariate analyses and CART modeling showed substantial variation in the presence of fentanyl in UDT among PWUD. Harm reduction services for people actively injecting drugs and drug checking programs based on capacity-building, empowerment, and targeted towards those not yet engaged in services are urgently needed to support PWUD in navigating the current volatile drug supply.

* Correspondence to: Department of Epidemiology, Brown University School of Public Health, 121 South Main Street, Providence, RI 02912, USA.
E-mail addresses: Leah_shaw@brown.edu (L.C. Shaw), katie_biello@brown.edu (K.B. Biello), jane.buxton@ubc.ca (J.A. Buxton), jacqueline_goldman1@brown.edu (J.E. Goldman), SHADLAND@mgh.harvard.edu (S.E. Hadland), ssherman@jhu.edu (S.G. Sherman), yu_li1@brown.edu (Y. Li), alexandria_macmadu@brown.edu (A. Macmadu), Brandon_marshall@brown.edu (B.D.L. Marshall).

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1. Introduction

Over 107,000 people died in the United States (U.S.) from drug overdose in 2022 ("CDC - Data Briefs, 2024; "SUDORS Dashboard, 2024). The rate of drug overdose death has been increasing since 1999, and more than one million people in the U.S. have died since then (Drug Overdose Deaths, CDC). The scope of the overdose epidemic in the U.S. is well documented, with over 75 % of these deaths involving opioids in 2021 (N. I. on D. A. NIDA, 2024). Additionally, the age-adjusted rates of fatal overdoses involving synthetic opioids such as fentanyl (and excluding methadone) increased dramatically from 2001 through 2021, and synthetic opioids are now major contributors to overdose deaths (Spencer et al., 2024). Polysubstance use is also increasingly recognized as a driver of overdose deaths, and it is estimated that in 2019, 63 % of fatal overdoses involved more than one substance (O'Donnell, 2020; "Polysubstance Use Facts, 2023). These mortality statistics do not capture the role of nonfatal overdose, the effects on both communities and the healthcare system as a whole, or added morbidity and mortality stemming from the overdose epidemic.

The U.S. drug market is characterized by an unregulated and rapidly evolving supply, with the introduction of fentanyl and other synthetic opioids into northeastern U.S. states beginning in 2013 ("Notes from the Field, 2024; Scholl et al., 2018). New England's unregulated opioid supply is increasingly dominated by fentanyl. In Rhode Island, the smallest state in the U.S. with a population of about one million people, 75 % of overdose deaths in 2022 involved fentanyl (Rhode Island Gov (RI GOV), 2024). Toxicology drug surveillance testing data done in Rhode Island suggest that drugs purchased on the street contain complex mixtures of substances (P. O. R. Local Drug Supply, 2023). People who use drugs (PWUD) are increasingly aware that substances sold as "dope" or heroin may contain substances such as fentanyl and its analogs, codeine, xylazine, benzodiazepines, and/or morphine analogs (P. O. R. Local Drug Supply, 2023; Collins et al., 2024; Mars et al., 2018). Additionally, proportions of fatal overdoses in the U.S. involving both fentanyl and stimulants rose from 0.6 % in 2010 to 32.3 % in 2021; this commonly is known as the fourth wave of the opioid epidemic (Friedman and Shover, 2023).

The rapidly changing drug supply highlights that it is particularly important for PWUD to have agency over their drug use in order to use more safely and avoid unintended overdose (Weicker et al., 2020). Previous research has demonstrated that there is minimal concordance between self-reported fentanyl use and actual exposure to fentanyl, and has called for the use of drug checking programs to improve peoples' understanding of the substances they are using (Park et al., 2022). As the drug supply continues to shift, people must have the tools to make empowered and informed choices about their drug use. Another study demonstrated that PWUD are becoming more aware of fentanyl in the drug supply, and understand the utility of tools such as fentanyl test strips and medications for opioid use disorder to help decrease overdose risk (Shin et al., 2022). Local governments, departments of health, and other policy makers must consider the drug supply and local context when planning and implementing evidence-based interventions.

The primary aim of this study is to identify subpopulations of PWUD at the greatest likelihood of fentanyl exposure, examine the extent and key predictors of recent fentanyl exposure based on results of urine drug testing (UDT), and better understand the relationship between self-reported drug use and objective presence of fentanyl exposure based on results of UDT. We hypothesized that a high proportion of PWUD in Rhode Island will have evidence of recent fentanyl exposure, even among those who prefer not to use fentanyl and those who do not report or were unaware that they had used fentanyl. With almost three-quarters of overdose deaths related to illicit fentanyl in Rhode Island in 2022 (Rhode Island Gov (RI GOV), 2024), this analysis is essential to better understand the knowledge, preferences, and experiences of PWUD to ultimately guide harm reduction oriented public health interventions such as drug testing programs and outreach efforts and save lives.

2. Materials and methods

2.1. Study design and participants

We analyzed baseline assessments from the Rhode Island Prescription and Illicit Drug Study (RAPIDS), a clinical trial studying whether a combination of providing fentanyl test strips and a behavioral intervention can reduce overdose risk. The trial protocol and study methods have been published previously (Jacka et al., 2020). In brief, the study recruited 509 PWUD, who either received naloxone and a brief training (standard of care) or standard of care plus fentanyl test strips and more in-depth fentanyl overdose prevention training (intervention). Study participants were recruited from harm reduction organizations, public advertising (e.g., bus ads), and word of mouth. Inclusion criteria included Rhode Island residents, ages 18 to 65, the ability to complete a survey in English, and self-reported use of illicit drugs or injection drug use in the past 30 days. Although the trial is longitudinal in nature, only baseline data were utilized for our study. Recruitment occurred between August 2020 and February 2023.

The Brown University Institutional Review Board reviewed and approved this protocol.

2.2. Measures of interest

2.2.1. Outcomes of interest

The central outcome of interest is the presence or absence of fentanyl in UDT performed at baseline. All urine testing occurred after the survey and interventions were completed, and test results were processed by trained study staff. The Rapid Response™ Multi-Drug Urine Test Cup manufactured by BTNX Inc. was used ("BTNX and Products.", 2024); 13 drugs were tested for, but only fentanyl results are described here. Although results were not routinely shared with participants, results were shared if requested by a participant. All results were entered into a secure platform, which also underwent routine quality assurance by lab staff for errors in data entry or processing. All testing materials and biological samples were stored and disposed of per BTNX Inc. and Brown University protocols.

2.2.2. Exposures of interest

Covariates of interest were included based on *a priori* knowledge, previous literature, and available information. Sociodemographic characteristics of interest included age, biological sex at birth (male, female), current gender identity (male, female, transgender/other), race/ethnicity (white non-Hispanic, Black non-Hispanic, non-Hispanic of another race(s), Hispanic/Latine of any race; refused/unknown), primary language spoken at home (English, Spanish, other), and education (beyond high school/equivalent degree, not beyond high school/equivalent degree) were included, as well as current individual monthly income level including public assistance and family support ($0-$500, $501-$1500, $1501 or more; asked in U.S. dollars), being unhoused in the past month (no, yes). Being unhoused in the past month was determined by an affirmative answer to "not having a regular place to stay, living in a shelter because of nowhere else to go, or living in a place not ordinarily used for sleeping, like an abandoned building, car, or park". The period of study enrollment (2020–2021, 2022–2023) was also included.

Covariates specifically related to substance use practices are as follows: past-month use of fentanyl test strips (no, yes), past-month and lifetime history of injection drug use (no, yes), current smoking, snorting, or swallowing modality of use (no, yes), past three-day stimulant use, and past month overdose (no, yes). Past three-day suspected fentanyl use was collected based on suspected fentanyl contamination in other substances. Participants were asked to only report extra-medical use, or use of drugs not under the direction or prescription of a

clinician. Of note, it is not possible to determine if this contamination was intentional or unintentional. Interviewers asked participants, "What drugs have you used that you were confident contained fentanyl in the past 3 days without a prescription or not as doctor directed?" The questionnaire then assessed known fentanyl contamination in multiple drugs, such as methamphetamine, cocaine, and heroin, among others. Participants were able to report which specific type of drug they believed to contain fentanyl in the 3-day lookback period. We defined past 3-day fentanyl use as suspected fentanyl contamination in any type of class of drug.

Other questions related to fentanyl were also included in this analysis, including preference for fentanyl. A five-point Likert scale was asked to measure agreement with the following statement: "I prefer using fentanyl or drugs that have fentanyl in them" (strongly agree, agree, neutral, disagree, strongly disagree). Lastly, the frequency of fentanyl use was assessed by asking "In the last month, how often have you used fentanyl or drugs you were confident contained fentanyl?" Participants could answer "never," "once or a couple of times," "once a month," "at least every week," or "every day."

2.3. Statistical analysis

We calculated baseline descriptive statistics of sociodemographic and substance use related characteristics stratified by the presence or absence of fentanyl in UDT. Pearson's Chi-square tests (Fisher exact tests when cell size <5) were used to measure associations between categorical variables and presence of fentanyl in UDT, and two-sample *t*-tests were used to compare continuous variables with the presence of fentanyl in UDT.

To better understand subpopulations with varying risk profiles of fentanyl exposure, we built a classification and regression tree (CART) model. These models are heuristic tree methods that highlight the relationship between one outcome and a group of predictors, and are helpful to identify cases that are likely to belong to a certain group through segmentation, to assign cases to a category through stratification, identify interactions, and create predictions for future events (Using Classification and Regression Trees: a practical primer). These models are nonlinear and nonparametric in nature, and partitions predictor variables at key cut points (Breiman et al., 2017). Both the structure of the CART model and the interpretation of the terminal nodes provide useful information. The terminal nodes show the probability of the outcome for each group, and the included predictors allow readers to describe the key characteristics of each group (Using Classification and Regression Trees: a practical primer). The colored shading of the nodes indicates likelihood of fentanyl presence in UDT. Green indicates likelihood <0.250; yellow indicates likelihood of ≥0.250 and <0.750; red indicates likelihood of ≥0.750.

CART modeling necessitates binary covariates; recategorization was based on previous literature and/or along the mean ("RPubs - Classification and Regression Trees CART, 2024). Each branch in the decision tree is made to maximize sensitivity and specificity and minimize the misclassification rate. Since only 4 observations had missing data, we did not impute or fill in this information, but these participants were excluded from the CART analysis. Each non-binary covariate of interest was recoded into binary categorical variables. Details about how variables were recoded are summarized as footnotes in Fig. 1. Self-reported past month frequency of fentanyl use was excluded due to high degree of correlation with other predictors and the outcome of interest. We first fit a classification tree using the training set and evaluated its performance using the test error rate, which we later compared to other models. Of note, the overall findings were similar between test and training sets. The training set used 300 randomly selected observations, which is about two-thirds of the overall dataset. The remaining 142 observations were then used as the test set for model prediction, and are shown in the results section. The algorithm determines which predictors are the most important determinants of the outcome, and it was determined that four decision splits would garner the best results. After model pruning and error reduction, the final model showed a misclassification rate of 18 %; based on the results there was not concern about overfitting. This means that, based on the predictors included, the model would correctly predict fentanyl presence in UDT 82 % of the time. All model splitting, pruning, and error reduction techniques were used based on best practices laid out in RPubs ("RPubs - Classification and Regression Trees CART, 2024). Data were analyzed using STATA version 16 for the descriptive statistics and correlations and R version 4.2.3 with packages rpart and rpart.plot for the CART modeling (Milborrow, 2024; R Core Team; "StataCorp.", 2019; Therneau et al., 2023; Wickham et al., 2024).

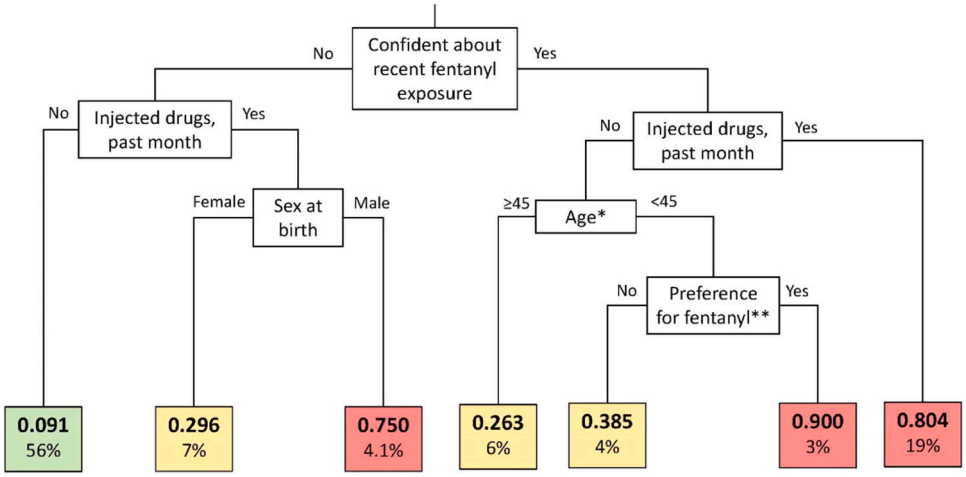

Fig. 1. Estimating the likelihood of fentanyl presence in urine drug testing among PWUD in Rhode Island using a classification and regression tree (CART) model. Notes: (1) Model trained with 300 observations and subsequently tested on remaining 142. observations. Four observations were dropped due to missing data. Model misclassification rate is 18.31 %. (2) Colors indicate likelihood of fentanyl presence in UDT. Green indicates likelihood <0.250; yellow indicates likelihood of ≥0.250 and <0.750; red indicates likelihood of ≥0.750. (3) Variable recategorization: *Age was recategorized into binary variable: ≥45 years old versus <45 years old; **Preference for fentanyl was categorized into binary 'no' (strongly disagree, disagree) or 'yes' (neutral, agree, strongly agree). (4) Percentages represent proportion of total sample.

3. Results

3.1. Baseline characteristics

UDT was not required for baseline survey completion. Eighty-eight percent (446 of 509) of enrolled participants completed UDT and were thus eligible for inclusion in this analysis. Persons who completed UDT were more likely to report past month injection drug use and more likely to be confident about recent fentanyl exposure as compared to those who did not complete UDT. Otherwise, these groups did not differ across any other sociodemographic or behavioral characteristics (see Table S1).

Among the 446 participants who completed both the questionnaire and UDT at baseline, the mean age was 43 years, 32 % identified as cisgender female, 52 % identified as non-Hispanic white, and 57 % were unhoused in the past month. Importantly, 31 % of participants had fentanyl present in UDT. Additionally, 30 % had injected drugs within the past month, and 20 % had used fentanyl test strips in the last month. Eighteen percent of participants stated they use fentanyl every day, and 15 % stated they preferred or strongly preferred fentanyl. Conversely, 41 % stated they "never" used fentanyl in the past month, and more than three-quarters of participants stated they "disagree" or "strongly disagree" preferring fentanyl (44 % and 32 %, respectively). Lastly, 33 % of participants were confident that they had been exposed to fentanyl in the last three days.

3.2. Factors associated with fentanyl presence in UDT

Table 1 stratifies participants based on the absence or presence of fentanyl in UDT. Those with fentanyl present in UDT tended to be younger (mean age 39.6 years; $p<0.001$), non-Hispanic white ($p<0.001$), lower monthly income ($p=0.001$), had used fentanyl test strips in the last month ($p<0.001$), had injected drugs in the past month ($p<0.001$), used stimulants in the past three days ($p=0.004$), were confident they had used fentanyl in the past three days ($p<0.001$). While past 3-day suspected fentanyl exposure and fentanyl presence in UDT were highly correlated, we note that only 95 (68 %) of the 139 participants with fentanyl positive UDT were confident they had been recently exposed (Table 1).

Prevalence of fentanyl in UDT showed an increasing gradient (or trend) at each level of response for reported frequency of fentanyl use, ranging from 13 % for those who reported "never" using fentanyl in the past month to 76 % for those who reported "every day" fentanyl use during the past month (Figure S1). Preference for fentanyl showed a negative gradient, with those who preferred to avoid fentanyl having a much lower likelihood of fentanyl presence in UDT (Figure S2).

3.3. CART modeling

When building the CART model, many covariates were determined to be important, with the first decision tree node determined to be confidence about recent (past 3 day) fentanyl exposure (Fig. 1). The second most important variable was past month injection drug use. In the final CART model, three groups were found to have the greatest likelihood of presence of fentanyl in UDT and are shown in red in Fig. 1. These groups were those who were confident they had been exposed to fentanyl in the last three days and who had injected drugs in the past month (likelihood=0.80). Additionally, those who said they were confident about being exposed to fentanyl, younger than 45 years of age, preferred fentanyl, but who had not injected drugs in the past month, were at a 0.90 likelihood of fentanyl presence in UDT. The only group who fell into the higher likelihood classification that did not think they had recently been exposed to fentanyl included people who had injected drugs and were male (likelihood=0.75).

Three groups were at a moderate likelihood of fentanyl presence in UDT and are shown in yellow in Fig. 1. Two of the three groups include those who stated they had been recently exposed to fentanyl but had not

Table 1
Baseline sociodemographic and substance use related characteristics of study sample stratified by whether fentanyl was present/absent in UDT (N=446).

Characteristic	Fentanyl not present in UDT 307/446 (68.8 %)	Fentanyl present in UDT 139/446 (31.2 %)	Total n (446)	*P*-value
Sociodemographic				
Age in years, mean (SD)	44.6 (11.3)	39.6 (9.9)	446	<0.001[‡]
Gender identity				0.047[b]
Male (cisgender)	190 (61.9)	94 (67.6)	284 (63.7)	
Female (cisgender)	99 (32.3)	44 (31.7)	143 (32.1)	
Transgender/Other	16 (5.2)	1 (0.72)	17 (3.8)	
NA	2 (0.65)	0 (0.00)	2 (0.45)	
Biological sex assigned at birth				0.644[a]
Male	203 (66.1)	95 (68.3)	298 (66.8)	
Female	104 (33.9)	44 (31.7)	148 (33.2)	
Race/ethnicity				<0.001[b]
Non-Hispanic white	143 (46.6)	89 (64.0)	232 (52.0)	
Non-Hispanic Black	62 (20.2)	10 (7.2)	72 (16.1)	
Non-Hispanic other/ multiracial	39 (12.7)	9 (6.5)	48 (10.8)	
Hispanic/Latine	62 (20.2)	31 (22.3)	93 (20.9)	
NA	1 (0.33)	0 (0.00)	1 (0.22)	
Home language				0.847[a]
English	241 (78.5)	112 (80.6)	353 (79.2)	
Spanish	52 (16.9)	22 (15.8)	74 (16.6)	
Other	14 (4.6)	139 (3.6)	19 (4.3)	
Education: beyond high school/GED				0.204[a]
No	193 (62.9)	96 (69.1)	289 (64.8)	
Yes	114 (37.1)	43 (30.9)	157 (35.2)	
Monthly income				0.001[a]
$0 - $500	121 (39.9)	79 (57.3)	200 (45.4)	
$501 - $1500	158 (52.2)	45 (32.6)	203 (46.0)	
>$1501	24 (7.9)	14 (10.1)	38 (8.6)	
Unhoused, past month				0.647[a]
No	133 (43.3)	57 (41.0)	190 (42.6)	
Yes	174 (56.7)	82 (59.0)	256 (57.4)	
Period of enrollment				0.060[a]
2020–2021	162 (52.8)	60 (43.2)	222 (49.8)	
2022–2023	145 (47.2)	79 (56.8)	224 (50.2)	
Substance use				
Overdose, past month				0.902[a]
No	287 (93.49)	124 (89.21)	411 (92.15)	
Yes	19 (6.19)	15 (10.79)	34 (7.62)	
NA	1 (0.33)	0 (0.00)	1 (0.22)	
Use of fentanyl test strips, past month				<0.001[a]
No	265 (86.6)	90 (64.8)	355 (79.8)	
Yes	41 (13.4)	49 (35.3)	90 (20.2)	
Injection drug use, ever				<0.001[a]
No	166 (54.1)	28 (20.1)	194 (43.5)	
Yes	141 (45.9)	111 (79.9)	252 (56.5)	
Injection drug use, past month				<0.001[a]
No	259 (84.4)	55 (39.6)	314 (70.4)	
Yes	48 (15.6)	84 (60.4)	132 (29.6)	
Smoking, snorting, or swallowing drugs, current				0.375[a]
No	40 (13.0)	14 (10.1)	54 (12.1)	
Yes	267 (87.0)	125 (89.9)	392 (87.9)	
Any stimulant use, past 3 days				0.004[a]
No	106 (34.5)	29 (20.9)	135 (30.3)	
Yes	201 (65.5)	110 (79.1)	311 (69.7)	
Confident in fentanyl use, past 3 days				<0.001[a]
No	254 (82.7)	44 (31.7)	298 (66.8)	
Yes	53 (17.3)	95 (68.4)	148 (33.2)	

(*continued on next page*)

Table 1 (*continued*)

Characteristic	**Fentanyl not present in UDT 307/446 (68.8 %)**	**Fentanyl present in UDT 139/446 (31.2 %)**	**Total n (446)**	***P*-value**
Fentanyl use frequency, past month				<0.001[b]
Never	160 (52.1)	24 (17.3)	184 (41.3)	
Once/a couple of times	77 (25.1)	30 (21.6)	107 (24.0)	
At least every week	24 (7.8)	26 (18.7)	50 (11.2)	
Every day	19 (6.2)	59 (42.5)	78 (17.5)	
Don't know/refused	10 (3.3)	0 (0.0)	10 (2.2)	
Preference for fentanyl or drugs that contain fentanyl				<0.001[b]
Strongly disagree	127 (41.4)	15 (10.8)	142 (31.8)	
Disagree	142 (46.3)	55 (39.6)	197 (44.2)	
Neutral	19 (6.2)	17 (12.2)	36 (8.1)	
Agree	14 (4.6)	38 (27.3)	52 (11.7)	
Strongly agree	2 (0.7)	14 (10.1)	16 (3.6)	
Don't know/refused	3 (1.0)	0 (0.0)	3 (0.7)	

‡ Two-sample T-test p-value
a Pearson's Chi square *p*-value
b Fisher's Exact test *p*-value
Note: "NA" groups not included in bivariate calculations and include those who answered, "Don't know/refused to answer."

injected drugs in the past month; those either 45 or older or who were younger but stated they did not prefer fentanyl were at 0.26 and 0.39, respectively. Lastly, females who had recently injected drugs but did not think they had been exposed to fentanyl were at a moderate likelihood of fentanyl in UDT at 0.30.

One group, shown in green on the figure, was at the least likelihood of fentanyl presence in UDT. This group includes people who did not think they had been exposed to fentanyl in the past three days and who had not injected drugs in the past month. The likelihood of this group having fentanyl present in UDT was 0.09.

4. Discussion

The primary aim of this analysis was to understand the factors associated with the presence of fentanyl in UDT, including self-reported substance use as well as demographic and other drug use characteristics (such as the use of fentanyl test strips, recent injection drug use, and recent overdose). We built a CART model to identify the subpopulations with the least and greatest risk of fentanyl in UDT with the goal of informing public health and harm reduction centered interventions. Modeling showed that confidence about recent fentanyl exposure, recent injection drug use, male biological sex at birth, younger age, and preference for fentanyl were all associated with fentanyl presence in UDT.

We found strong gradients between recent fentanyl exposure based on UDT and both self-reported past month use of fentanyl and preference for fentanyl among this sample of PWUD. The CART results also demonstrated that the most important determinant of fentanyl presence in UDT was suspected past 3-day intentional or unintentional exposure. These findings demonstrate that many PWUD are aware of recent exposure to fentanyl. Qualitative studies support this, and show that PWUD are well aware of the increased prevalence of fentanyl in the drug supply, the expansion of the types of drugs that may contain fentanyl, and the overall unpredictability of the drug supply (Shin et al., 2022; Duhart Clarke et al., 2022). Another study from Vancouver demonstrated that among participants who had tested positive for fentanyl through urine drug screening, about half had suspected/known they had been exposed during self-reported questionnaires (Hayashi et al., 2021). Nonetheless, future research should seek to better understand intentional versus unintentional exposure to fentanyl, and test interventions such as drug testing kits/programs to identify how PWUD are able to make decisions about which drugs they prefer to use. Additionally, although those who recently injected drugs were at a greater likelihood of fentanyl exposure, research and public health interventions must also include people who use through other modalities such as smoking and snorting to ensure those populations are also well connected to harm reduction services such as overdose prevention centers and fentanyl test strips and not excluded from messaging about the drug supply and overdose risk.

Two demographic characteristics emerged as important predictors of fentanyl presence in UDT in the CART model: biological sex at birth and age. Among those who did not think they had recently been exposed to fentanyl but had injected drugs in the past month, the likelihood of fentanyl presence in UDT was 0.75 for males yet only 0.27 for females. Some evidence has shown that women may be more likely to self-report unintentional fentanyl exposure compared to men, but it is unclear how those results would translate when not differentiating between intentional and unintentional exposure (Mitra et al., 2020). Another study found no differences in fentanyl preference by gender, but preferences were differential by past-year overdose history, among other factors (Morales et al., 2019).

The likelihood of fentanyl present in UDT was different when comparing those younger than 45 years old to those 45 years and older. Among those who thought they had been recently exposed to fentanyl but who had not recently injected drugs, older adults had a 0.26 probability of having fentanyl present in UDT, whereas the probability of younger adults having fentanyl present in UDT ranged from 0.39 to 0.90, depending on self-reported preference for fentanyl. Past research has shown that younger adults tended to prefer fentanyl more than older adults, possibly highlighting an age-cohort effect, since fentanyl was introduced into the drug market only about a decade ago (Morales et al., 2019). Qualitative findings among people who use fentanyl in Boston also showed that older adults had a stronger aversion to fentanyl and its lethality compared to younger adults. Results highlighted that older adults tended to be more concerned about both fatal and nonfatal overdose compared to younger adults (Gunn et al., 2021). Although federal and state agency reports about the opioid overdose epidemic primarily center statistics based on overdose death, it is necessary to consider that these deaths may also be considered drug poisonings (Hoffman, 2024). The present analysis framed these events as overdose, in alignment with the framing of the survey, but it is nonetheless an important reminder that overdose in this country is closely tied to the poisonous drug supply.

This study is subject to several limitations. First, the sample of PWUD in Rhode Island may not actually be representative of the full diversity of PWUD in the state. Given the recruitment approach, we may have undersampled those who only use drugs within the "club scene" or who are the most marginalized and stigmatized (e.g. people who engage in transactional sex, people of color, and LGBTQIA+ groups). Second, the short lookback period for self-reported substance use is both a strength and limitation of this work. Even if someone was able to avoid fentanyl during a three-day period, it becomes more unlikely that someone is able to avoid this drug if they are using other substances purchased on the street over a longer period of time. Conversely, because the self-reported questionnaire was limited to a short lookback period, we were able to capture acute periods of time that aligned with the duration of fentanyl and its metabolites in urine (about 72 hours) (Silverstein et al., 1993), which many other larger scale studies are unable to do. Relatedly, since fentanyl exposure is measured from a single urine test, and thus may not capture exposure outside of that short lookback period. Third, 446 of the original 509 participants recruited at baseline completed UDT, but the remaining 63 (12 %) participants did not and were thus excluded from this analysis. The excluded participants were much less likely to report past-month injection drug use and suspected past 3-day fentanyl

exposure. Given that these factors were both positive predictors of fentanyl presence in UDT, the prevalence of recent fentanyl exposure could be overestimated in the sample that provided UDT. Finally, although BTNX states that routine checks are made to evaluate the sensitivity and specificity of their tests, the specific numbers are not published and thus not known.

5. Conclusions

Participants who self-reported recent fentanyl exposure were at an increased likelihood of the presence of fentanyl in quantitative urine testing, and we found that injection drug use, preference for fentanyl, younger age, and male sex all increase the likelihood of fentanyl in UDT. Evidence-based solutions are urgently needed to support PWUD to understand the composition of the substances they are taking and the risk that unregulated drugs purchased may unknowingly contain fentanyl (or other drugs). Tools centered on harm reduction and capacity building to support safer decision making around drug use will be helpful to slow the spread of infectious diseases, support the connection to health care services and stable housing, and prevent overdose and overdose death.

CRediT authorship contribution statement

Jane A. Buxton: Conceptualization, Supervision, Writing – review & editing. **Jacqueline E. Goldman:** Conceptualization, Data curation, Writing – review & editing. **Leah C. Shaw:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Katie B. Biello:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Brandon David Lewis Marshall:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Alexandria Macmadu:** Conceptualization, Methodology, Supervision, Validation, Writing – review & editing. **Susan G. Sherman:** Conceptualization, Writing – review & editing. **Yu Li:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – review & editing. **Scott E. Hadland:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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Potential conflicts of interest

Dr. Biello reports receiving unrestricted research funds from Merck outside the submitted work. Dr. Sherman is an expert witness in ongoing opioid litigation. No other co-authors have interests to disclose.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dadr.2024.100280.

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